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Use of cellular automata in the study of variables involved in land use changes

An application in the wine production sector

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Abstract The study of changes in land use has been included lately in territorial processes in order to optimize future management decisions. The different functions that the territory plays (production, aesthetic, and natural functions, etc.) make planning choices more difficult. This work focuses on the selection and combination of a set of indicators to analyze the *variables* through which the changes occur in the land used in viticulture for wine production. The proposed approach makes use of the Geographic Information System (GIS) in the development of a map of land use scenario. It is applied to a case study through a model involving cellular automata (CA) implemented with maps of suitability for viticulture and Markov chains. The use in this case of the CA is aimed at validating the scenario map in order to deduce the variables and the orientations of the farmers in the field of wine production.

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Introduction

The study of changes in land use is among the new challenges in territorial planning. Investing in such an area of study would be advantageous due to the resources in the form of public funds and community aid that could be available for the creation of a diversified picture that takes into account the different territorial functions: functions of production, aesthetics, water regulation, territorial management, and natural features and the preservation of an identity to which the territory is strongly linked. To this end, it is of considerable interest to use data management software tools capable of analyzing the changes occurring during the previous years, relying on the acquired know-how as a starting point for further investigation.

In a particular way, the cellular automata (CA) are used in almost all land use change models for urban environments (Torrens and O'Sullivan 2001; Ward et al. 2000; White et al. 1997; Wu 1998). Besides urbanization, CA-based models now also simulate other processes of land use change; for example, Messina and Walsh (2001) studied land use and land cover dynamics in the Ecuadorian Amazon, an area where tropical forest is converted into agricultural land.

Applications of CA for land use change models in which both urban and rural land uses are considered are provided by Engelen et al. (1995) and White and Engelen (2000) (Verburg et al. 2004).

The analysis of changes in land use is coupled with the study of the rules of transition, the latter being characterized by variables that come into play in the evolutionary scenarios. "The definition of the transition rules of a CA model is the most essential part to obtain realistic simulations of land use and land cover change. Land use change is the result of a complicated decision-making process; however, the transition rules of CA models are often defined on an ad hoc basis" (Verburg et al. 2004).

The proposed case focuses on the selection and combination of a set of indicators to describe the transition variables and to create maps of suitability for viticulture. The CA are directly applied just to validate the aforementioned suitability maps which are used indirectly to validate the indicators employed for their creation: this will enable us to understand what may be the reasons currently driving or capable of driving farmers in the future to shift their attention or simply to persevere in viticulture activities.

In addressing this issue in certain regions of the Netherlands, Hagoort et al. (2008) have shown that regional and temporal calibration of neighborhood rules is a refinement in the application of CA-based land use models that pay off by increasing the validity of the model outcomes.

This paper aims to determine a set of indicators able to analyze the variables through which land changes occur in viticulture practices. In this work, the study area is represented by the southern spot of the province of Florence (Italy), in which the traditional vocation is to foster the growth of vineyards. In this area, agricultural activity is amalgamated with the history and the culture of a territory that has invested and is still investing a lot on grape and wine production. The proposed approach applies Geographic Information System (GIS) that allows the development of visual scenarios of changes in land use combining sophisticated mathematical algorithms with local customs and traditions. This generates a model that highlights learning gained from the changes that occurred in the past in order to define the variables that affect viticulture activity.

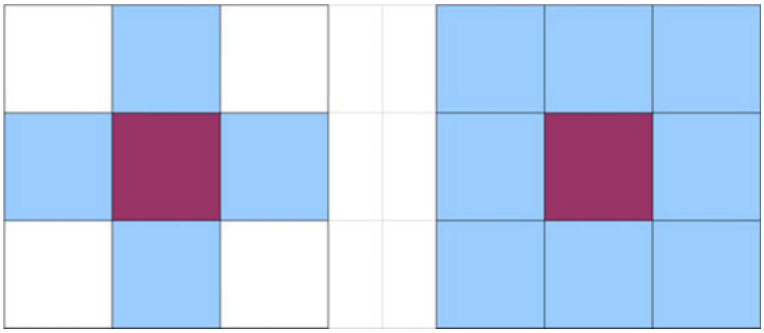
Applied methodology

CA is an instrument belonging to the field of artificial intelligence. Through CA, the use of simple behavioral rules allows simulation of the global behaviors of a given system. CA was designed in the 1950s and has recently found use in numerous software applications, in the field of urban and regional planning primarily for its interface compatibility with GIS (Engelen et al. 2002). The classical CA study can be described as having the following properties:

1. The *study area* is usually divided into cells, parts of a regular two-dimensional grid (typical grid raster). However, more recently three-dimensional and irregular grid CA systems have been used where each cell is identified by three coordinates forming a cube.
2. The *state of each cell* is determined through attributes; in the case of a GIS vector, punctual, linear, or polygonal elements from within the cell. In the case of a GIS raster the whole pixel.
3. It is then necessary to define the *rules of transition* from one state of the cell to another. This is based on both initial states of the cell and to the adjacent ones. Computer calculation is due to the fact that having k possible states and n cells included around the identified cell, there are possible rules (e.g., with k=2 and n=5, 4 billion rules are found). According to these rules it is possible to distinguish various typologies of CA: "deterministic" CA using rules of fixed evolution (where evolution trends are constant), "stochastic" CA where the transition rules are modified during the dynamics, and "probabilistic" CA using probability rules.
4. The cells adjacent to the examined one are defined as a neighborhood: the best known neighborhoods are those defined by J. Von Neumann and Moore (Fig. 1).
5. Definition of a temporal scale: The dynamics generally represent temporal rhythms of transition rules (evolution) of the cells. This takes place in "synchronous" and discrete ways, either changing thereby simultaneously the state of each cell at each step (in territorial applications the year or its multiple is matched) or not.

Practically and based on all of the above conditions "the cells then react, by a series of rules or relationships,

Fig. 1 Von Neumann and Moore neighborhoods



to the local conditions around the cells, for example, the condition of neighboring cells" (Smith and Smith 2007).

The CA method is used nowadays in many areas of knowledge: in physics, medicine, and chemistry. An area of application of noted interest is the simulation of urban phenomena, especially in the field of territorial planning (e.g., Engelen et al. 1999).

This paper describes the above mentioned applications by means of a CA implemented using *suitability maps* for viticulture (Creation of viticulture suitability maps Section) and Markov chains (Transition matrix Section) to develop a scenario map for year 2006 regarding the targeted area of study.

This synergy between the different tools is used to overcome two main limitations regarding the use of CA, as suggested by Bernetti and Marinelli (2008): "In a CA model the transitions are free, each cell can freely change its state; whilst in land use changes analysis it is essential to presume a final query for each typology of land use" (this issue was addressed by Markov chains); and "the space in which changes in land use occur is isotropic; the transitions depend only on the rules of the model and the state of the neighborhood cells. Conversely, the transformations in the land use of the area of research depend on the land uses of the surrounding areas and on their geographic and socioeconomic characteristics" (issue implemented by using the indicators for the development of suitability viticulture maps). Afterward, the created map resulting from the CA is compared with an existing land use map. A statistical validation would indirectly specify the reliability of the indicators used. The indicators are considered as factors that describe the preference towards viticulture by farmers. Figure 2 shows the flow chart of this manuscript.

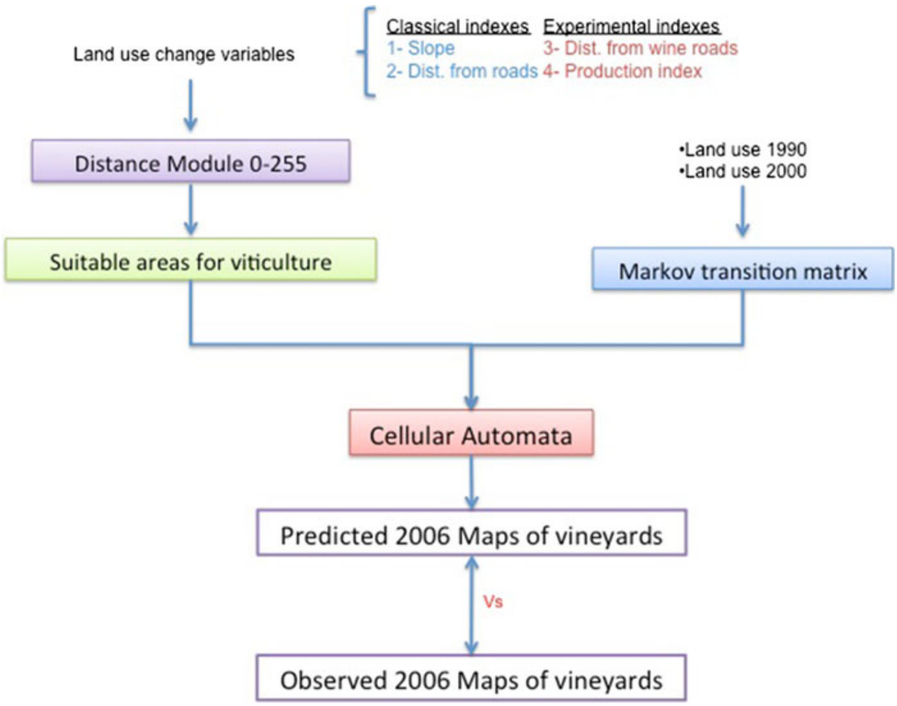
Areas of study

The traditional agricultural vocation considered in the areas of study is viticulture. Such areas extends along the southeast strip of the province of Florence, located in Central Italy (Fig. 3). The morphology of the area is hilly (over 40 % of the territory lies at an altitude ranging between 200 and 600 m above sea level), with average annual temperature of 18 °C, and rainfall of around 800 mm annually. The areas represent 13 municipalities, having about 12,900 ha of vineyards, and can be divided in two main categories based on the type of wine produced: the *Empolese Valdelsa* and the *Chianti Classico*.

For Empolese Valdelsa, five municipalities have been thoroughly analyzed: Cerreto Guidi, Empoli, Vinci, Capraia, Limite and Montelupo Fiorentino. This area of "Vino Bianco Empolese" is located in the north of the Empoli Valdelsa area. Bianco Empolese was founded in 1997 following a regional law (L.R. 29 May 1997, n. 38), and 4,380 ha of vineyards cover the area, equal to approximately 34 % of the overall examined surface (12,900 total ha).

In the second area, eight municipalities were examined: Montespertoli, Certaldo, San Casciano in Val di Pesa, Tavarnelle in Val di Pesa, Lastra Signa, Scandicci, and Greve in Chianti. The Chianti area has characteristics opposite to those of the Bianco Empolese area. Indeed, the Chianti area is rich in tradition, and a conservation policy was initiated many years ago to preserve and enhance local specialties. This is evident from the existence of the Chianti Wine Consortium since 1927. This consortium brings together more than 2,500 manufacturers affecting more than 10,000 ha of vineyards, and producing a volume of 70,000,000 l of Chianti wine each year. The vineyards of Chianti examined for this work extend over 8,600 ha, accounting for 66 % of the total study area.

Fig. 2 Methodology flowchart



Cellular automata for the definition of a land use map in 2006

Creation of viticulture suitability maps

Generally, at the territorial level, land use changes can be inferred either from what has happened in the past, or from identified situations related to pedologic, climatic, orographic, historic, etc., characteristics of the study area. In the case of this work the rules of transition (refer to Introduction Section) of the geographic surfaces surrounding the study areas are considered. As stated by Hagoort et al. (2008) the rules of transition consist of variables capable of driving the process

Fig. 3 Case study

of evolution of certain land uses which are determined based primarily on review of the literature and of interviews with industry experts. Furthermore, Hagoort et al. (2008), in view of the possible influence of the territory on such variables, identify different types of functions relating to the variables on the basis of their distance from the land use in question. It is, however, an area difficult to determine, and difficulty increases exponentially according to the land use considered (Dear 1977).

In this study, the suitability maps display for each cell a maximum approximate value (255) close to the considered variable. This value decreases (linearly) with increasing distance from the variable itself. These values directly affect the probability of the cell transformation in the vineyard.

Based on available data and on the examined literature (Lombardo et al. 2005; Pijanowski et al. 2002; Al-Ahmadi et al. 2009) two *classical variables and two experimental variables* were selected because of their capacity to influence the changes in land use:

1. Slope
2. Main roads
3. Ancillary roads (wine roads)
4. Productivity

No priority weights are attributed to the analyzed variables, classical and experimental; they are considered equally relevant in their involvement throughout the phases of the work. The two *classical variables* are represented by the slope and distance from main roads.

Considering that the climatic characteristics of the examined areas are particularly suitable for viticulture, no other variables normally affecting vineyards, such as temperature, humidity, precipitation or altitude, are measured.

Overall, 88 % of the studied areas slopes are less than 22 %, 55 % of which is below 10 %: it is effectively an area characterized by a very gentle relief. Vineyards can also be found on slopes that are greater than 20 % (*Greve in Chianti*) with the presence in some cases of terraced slopes. The areas with gradual slopes were considered suitable for wine-growing; this is justified only from an economic perspective and by the fact that the cost of the cultivation and harvest operations increases with the increase of slope. The slope map (layer) was obtained from the Digital Terrain Model (DTM) of Tuscany in raster format and a resolution of 75 m. In Fig. 4, the more gradual slopes are shown in dark red (values close to 255).

The study of the primary road network, representing the next variable, has shown that the entire area is characterized by a good road network that increases in proximity of major urban centers such as Empoli and Scandicci. Based on this variable, the areas near the main roads are considered particularly suitable for vine-growing, following the same viewpoint mentioned before (economic or fewer operation costs) for the slope. The adopted road network layer is based on the “road traffic” maps developed in 2003 by the region of Tuscany.

The suitability map for viticulture was drawn starting from the road network layer by calculating the distance from main roads to the related fuzzy distance. In Fig. 5, the dark red areas (values close to 255) show the ones next to the road network.

“The fuzzy distance decay membership function is used to indicate proximity to a given feature" (Al-Ahmadi et al. 2009). Rather than having a single crisp threshold that denotes a distance away from a feature, the fuzzy distance decay function is capable of describing the benefits of the vineyards' proximity to a particular variable (in this case the network of main roads).

Two *experimental variables* linked to the typical phenomenon of the study areas were then introduced: the existing distance from the “Strade del Vino” (wine roads), and the productivity of the quality vineyards (DOC and DOCG). Regarding the ancillary roads the work refers to the “wine trails” surveyed and geo-referenced by the region of Tuscany. These are paths within the territory characterized by a high vocation to wine culture, in addition to the vineyards and wineries, and by natural, cultural and historical attractions particularly significant for a holistic approach to wine tourism. The wine trails are an instrument for promoting rural territorial development, and are intended to encourage Eno-tourism.[1]

The study area considers two among 14 itineraries proposed by the Region of Tuscany: The Chianti wine of the Colli Fiorentini (Florentine Hills) and the Chianti of Montespertoli crossing by the four municipalities of Montelupo, Lastra a Signa, Scandicci, and

[1] Retrieved from website http://www.terreditoscana.regione.toscana.it/stradedelvino/ita/index-ita.html [last accessed October 12, 2011].

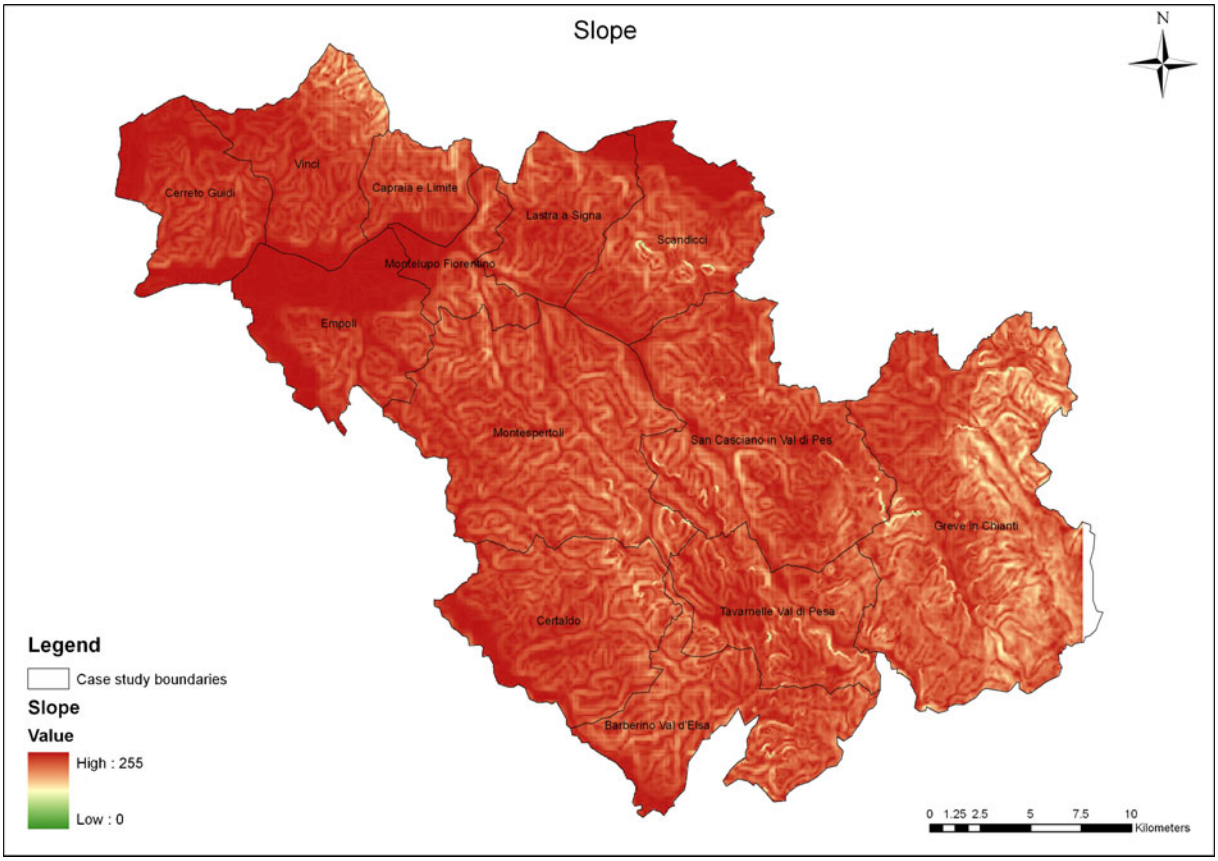


Fig. 4 Slope map

Montespertoli. From an operational point of view, the proximity to these roads is considered for its capacity to inspire the start of new vineyards, justifying this phenomenon also through an aesthetic factor. The wine roads are created to promote a particular territory, making viticulture its strong point, and influencing the surrounding areas to preserve or move towards the same vocation. In this case, too, the suitability map for viticulture was developed by calculating the fuzzy distance from the wine trails. In Fig. 6, the areas close to wine trails are shown in dark red (values close to 255).

The last variable considered is based on the productivity of the studied areas: specifically, the productions per hectare of the wine were examined and recorded over a period of time corresponding closely to that of the study. To develop suitability maps based on productivity, a specific index was created capable of selecting the areas that are particularly productive. The areas located in the proximity of the previously mentioned areas were considered as the most suitable for the cultivation of vines.

Relying upon the database provided by the Region of Tuscany Wine Production for Agricultural Allocations[2] (ARTEA), 216 quality (production of DOC and DOCG[3] wine) wine farms scattered in the area were geo-referenced. For each farm an average production per hectare during 2005–2009 was calculated, by applying formula 1.

$$P_{\mathrm{aj}} = \frac{\sum_{2005}^{2009} P_j}{N} \tag{1}$$

where P_{aj} is the annual average production per hectare of the jth farm, P_j is the annual production

[2] L'Agenzia Regionale Toscana per le Erogazioni in Agricoltura (ARTEA) is an agency that allocates funds as anticipated by EU communities regulations for the management of the Commune Agricultural Politics (CAP).

[3] DOC or DOCG or "Controlled Designation of Origin" is an Italian quality assurance label attributed to wine produced in small or medium scale areas, as per wine production standards.

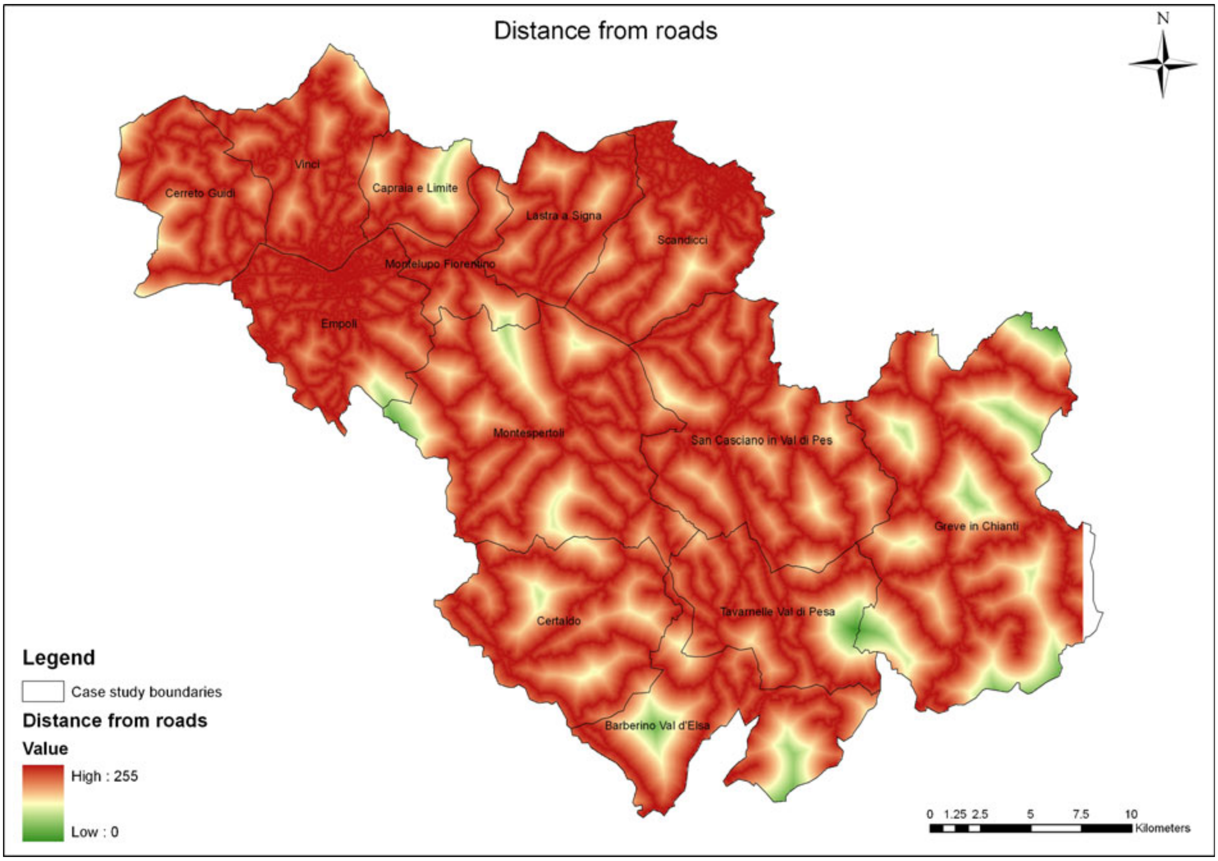


Fig. 5 Map indicating distance from main roads

per hectare of the *j*th farm, and *N* denotes the number of years considered.

The productivity was then normalized as illustrated in formula 2.

$$I_{pj} = \frac{P_a^{max} - P_{aj}}{P_a^{max} - P_a^{min}} \quad (2)$$

where I_{pj} is the normalized productivity index of the *j*th farm, P_a^{max} is the maximum value of annual average productions per hectare (refer to the total number of farms), P_a^{min} is the minimum value of annual average productions per hectare (refer to the total number of farms), and P_{aj} is the annual average production per hectare of the *j*th farm.

To identify the most productive farms, the analysis was based on the use of fuzzy logic quantifiers, applying, for conversion purpose verbal fuzzy numbers, an appropriate scale of linguistic terms based on those proposed by Chen and Hwang (1992). The adopted scale is based on the terms high and low degree of belonging to a particular group (in this case, it is represented by productivity groups). Using this scale typology, a high productivity degree was identified with a fuzzy value ranging between 0.25 and 1 (Fig. 7).

Among the approximately 12,900 ha of vineyard in the study area, 7 % (about 941 ha) are highly productive: these vineyards are mainly located in the municipalities of Greve in Chianti (27 %), San Casciano in Val di Pesa (19 %) and Barberino Val d'Elsa (10 %).

As for the variables relative to the primary and ancillary roads, the related areas of the map of viticulture suitability were finally developed by calculating the related fuzzy distance. In Fig. 8, the areas close to the highly productive vineyards are highlighted in dark red (values close to 255).

Transition matrix

The changes in land use between 1990 and 2000 are examined in this phase using the Markov chains.

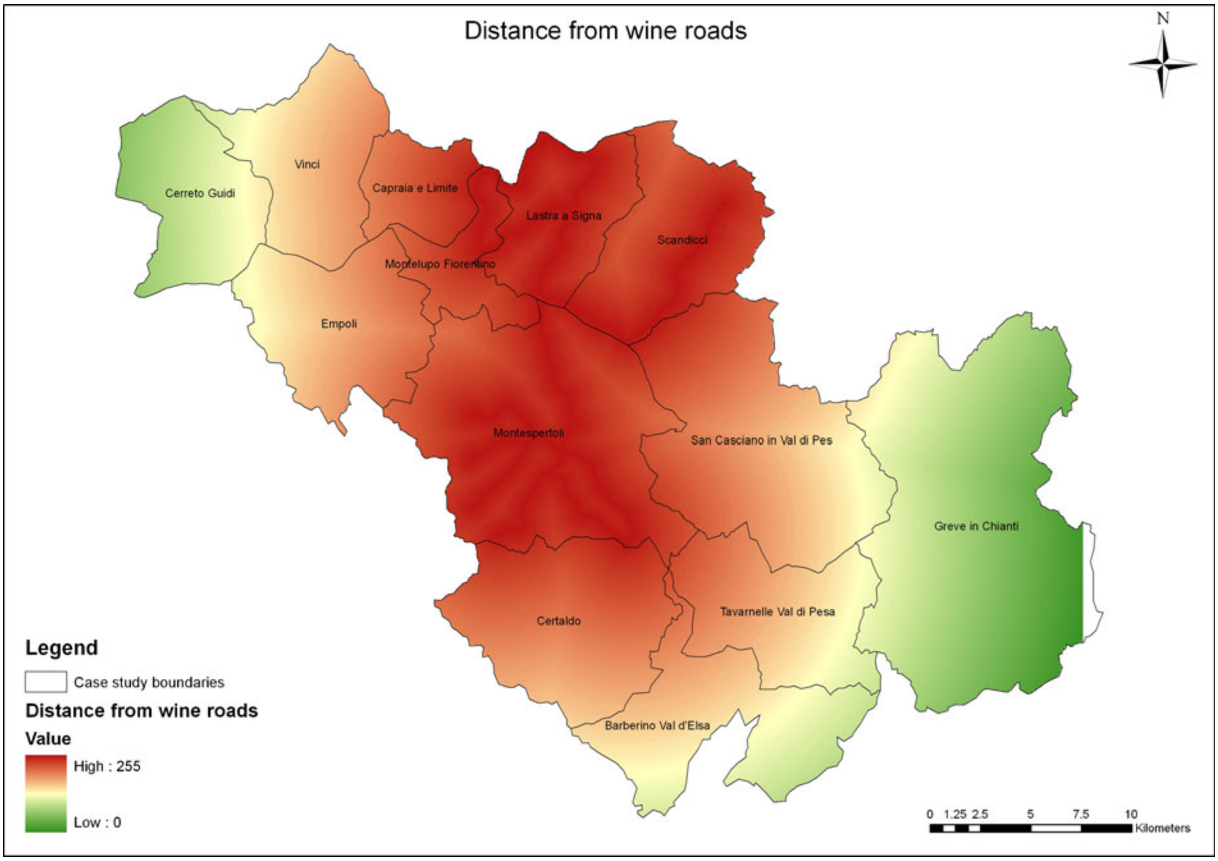


Fig. 6 Map of the distances from wine roads

Markov chains (Eastman and Toledano 2000), are defined as a stochastic process in order to calculate the transition probabilities from land use at time (t) to

Fig. 7 Linguistic scale adopted

land use at time (t)+1(1+1). For the calculation it will be necessary to rely on two maps relative to the time interval selected (t and t+1) allowing therefore, the estimation of the maximum likelihood of the probability of change through Eq. 3 (Bernetti and Marinelli 2008).

$$P_{l,l+1} = \frac{n_{l,l+1}}{\sum_{l+1} n_{l,l+1}} \quad (3)$$

where $P_{l,\ l+1}$ is the probability of transition from land use at time $t(l)$ to land use at time $(l+1)$ and $n_{l,l+1}$ is the total number of transitions.

Assuming a future development that maintains the trend occurring in the past, probabilities can then be displayed like a stochastic matrix $n \times n$ of values p_{ij} (Table 1).

As described by Coquillard and Hill (1997), the matrix obtained expresses a system that changes through discrete increments of time, in which the value of each variable at a given time is the sum of

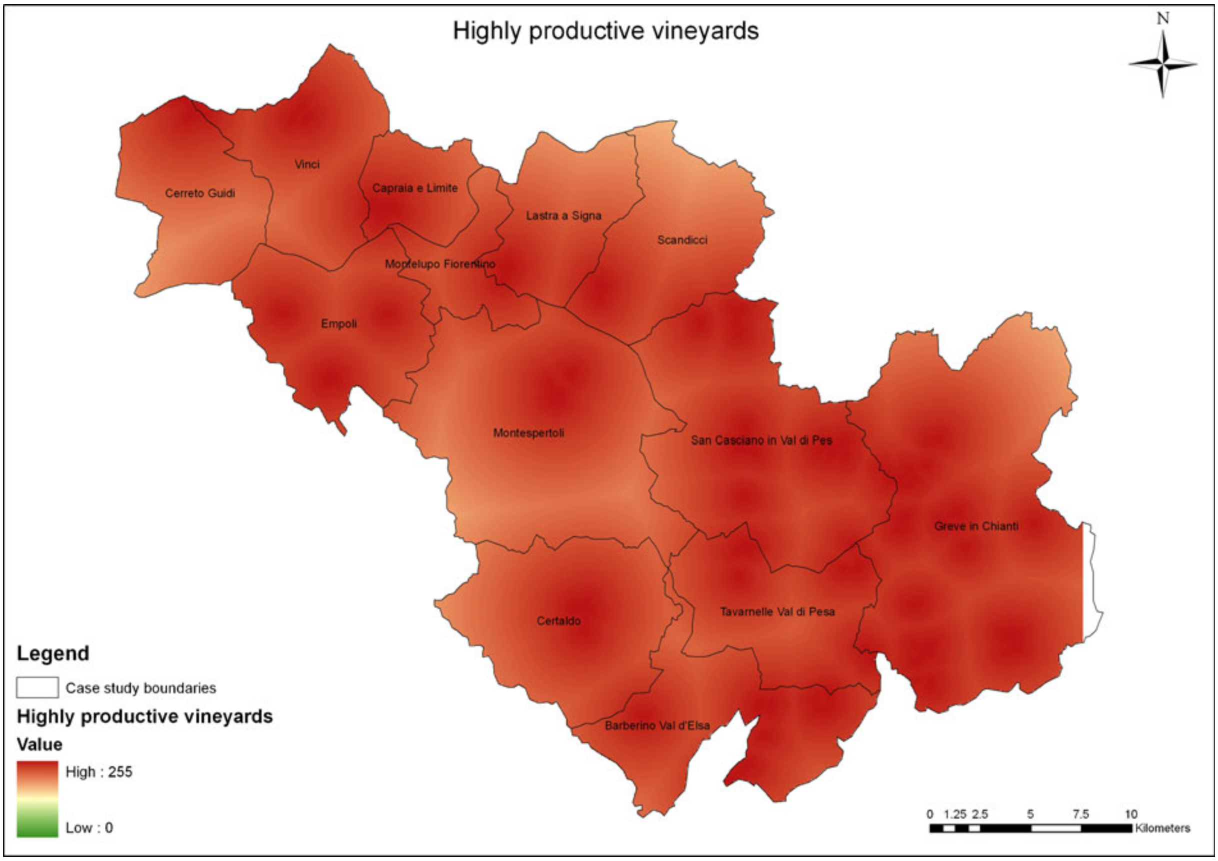


Fig. 8 Map of distances from highly productive vineyards

percentages of the values in the instant before. The sum of the fractions along a row of the matrix is equal to one, while the diagonal in the matrix contains the percentages of pixels that do not change between initial and final dates.

From an operational point of view, a transition matrix has been created at year 2006 (Table 2) based on changes between 1990 and 2000. Corine Land Cover European Geographic Information Standards (ENV 12657) is the reference source adopted for data availability and consistency of analysis.

The analysis that adopted a proportional error of 0.10 of the input maps[4] has shown that, in the process of conversion to vineyards, mainly heterogeneous agricultural areas and forests are involved.

Table 1 Probabilities matrix

	State i (t+1)		
State j (t)	p_{11}	p_{12}	p_{1n}
	p_{21}	p_{22}	p_{2n}
	p_{n1}	p_{n2}	p_{nn}

where n is the number of discrete states in the Markov chain, and p_{ij} is the transition probabilities (between 0 and 1) from state j to state i in time interval between t and t+1.

Implementation of the suitability maps and of the transition matrix in a cellular automata

The suitability maps for viticulture and the transition matrix derived from the Markov process were

[4] "The proportional error: a measure of uncertainty that can be assigned to the transition probability matrix according to each land cover class. This takes into account the error in the classification of the land use maps." (Tattoni et al. 2011). It is often set at 0.15-0.10 because a common value of accuracy for a land use map is 85 %–90 %.

Table 2 Transitions matrix of 2006

		Land use at time t+1 (2006)			
		Vineyards (%)	Agr. mix. areas (%)	Forest (%)	Other (%)
Land use at time t (2000)	Vineyards	90	0	0	0
	Agr. mix. areas	4	89	0	0
	Forest	2	2	90	2
	Other	2	2	2	90

used to implement a CA able to compute, through a Moore neighborhood of 5×5 pixels, a land use at year 2006; based on that, calculation of the vineyards' development can be highlighted. From an operational point of view the final result (Eq. 4; Engelen et al. 2002) is represented by a deterministic map of the land use scenario of year 2006 (derived map).

$$P_j = vS_jZ_jN_j \quad (4)$$

where P_j is the land use at year x of the jth pixel, v is a scalable random disturbance term,[5] S_j is the intrinsic suitability of the jth pixel (the result of a weighted sum of suitability maps), Z_j is the probable land use of the jth pixels deriving from Markov transition matrix, and N_j is the neighborhood effect assigning to the jth pixel the prevalent land use of the neighborhood in consideration.

The final prediction map (derivation map) was developed using the information previously calculated (transition matrix and suitability maps for viticulture) and by balancing the possible states of land use for each pixel.

As evoked by Berger et al. (2001a, b), all this is done through an iterative process that assigns each pixel (with high probability of belonging) to the respective classes of land use, in order to make use of all the pixels under each category. A pixel that has a high probability of realization for multiple classes is assigned to the category having the highest value.

As mentioned above, the map derived is the point of departure to emphasize not so much the changes in land use (in the present case the areas suitable for viticulture) as to understand if the variables used (slope, primary roads, ancillary roads, and productivity) can affect changes in land use.

The objective of the next section is the comparison between the 2006 map developed through the CA and a referenced land use map of the same year. If the statistical analysis validates the derived map, then it is possible to assert that the variables introduced in the model are an active part of the change scenario affecting the vineyards.

Validation of results

The time prospect is the year 2006, since it is the most recent year for which a land use map can be accessed and is comparable to the one obtained from the CA: the source was therefore based on Corine Land Cover as this was previously used to obtain the transitions matrix.

This map allows the comparison and validation of the process that led to the creation of a land use for the year 2006, and through the use of Markov chains, to the maps of land use suitability (Fig. 9). This process has indirectly revealed the appropriateness of the selected variables involved in the land use changes in the vineyards. To this end, the Cohen (Cohen's Kappa) concordance index was used with success for its simplicity and clarity of interpretation (Carletta 1996; Hagoort et al. 2008; Pontius 2000) through which the two compared maps have revealed a fair degree of conformity from both quantitative (number of pixels in the vineyard) and spatial points of view (i.e., checking the exact location of each pixel in both maps): two maps can have the same percentage of pixels for each class of land use, but different spatial allocations of these quantities. The study of spatial inconsistency is complex; it derives from a shift in position between pixels of different categories (Pontius and Schneider 2001). Index K was calculated to be equal to 0.9728.

Moreover, the statistics about vineyards surfaces confirm the good prediction of CA: derived map estimates about 13,128 ha of vineyards while reference map estimates about 12,990 ha (138 ha are probably missing due to the rounding of the model data). There are not differences in vineyards surface (between derived and reference map) in Greve in Chianti and

[5] "The deterministic value is given a stochastic perturbation (using a modified extreme value distribution), such that most values are changed very little but a few are changed significantly"(Engelen et al. 2002)

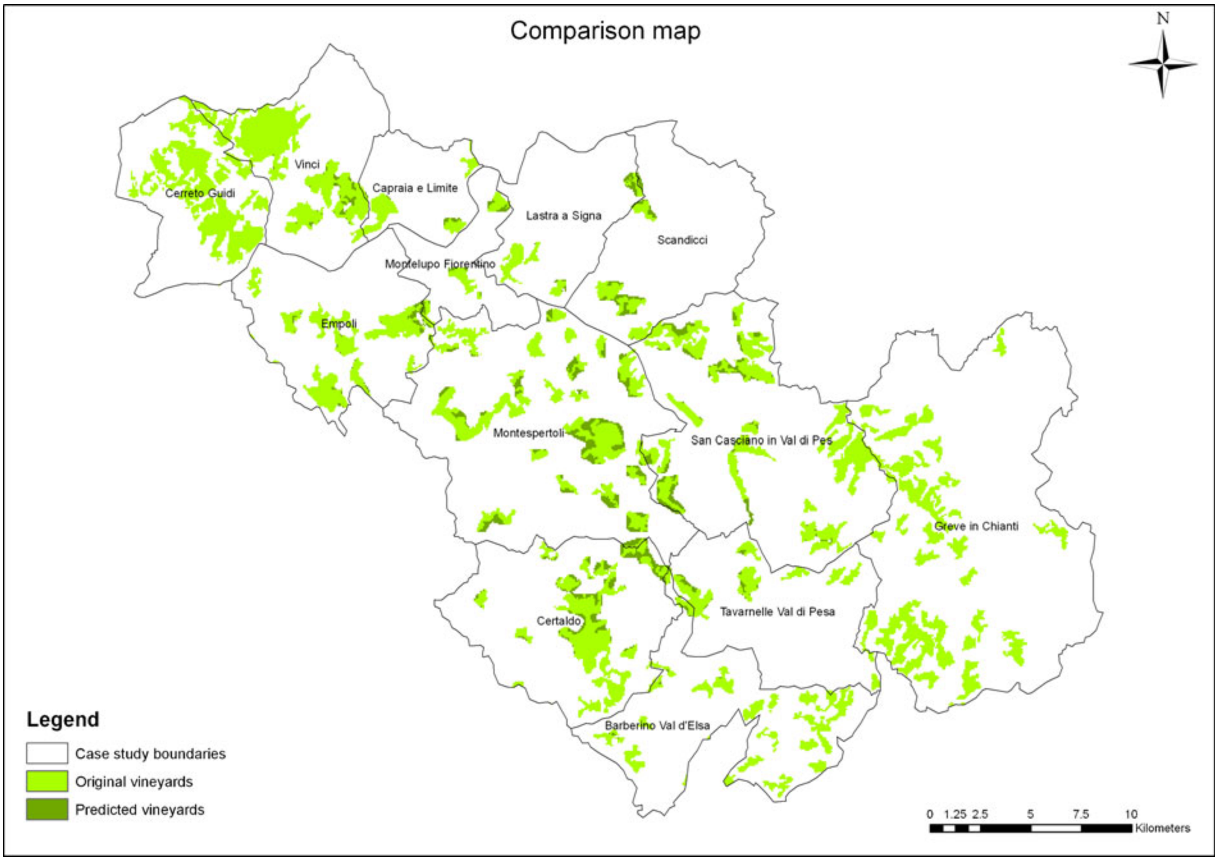


Fig. 9 Comparison between the derived map and the reference map

Cerreto Guidi municipalities, while the main differences in vineyards surface are mainly located in Montespertoli and Certaldo municipalities.

Once a good correlation between the pixel–pixel maps was found trough the analysis, the next step is to determine a possible correlation to the geographic analysis of the neighborhood of a given pixel: this would allow understanding which would be the appropriate spatial location of each land use, and of its neighborhoods. The study of the geographic neighborhood is a delicate theme. It was approached by Verburg et al. (2004) through a methodology enabling the analysis of the characteristics.

The method used for this purpose is based on a filter floating window (moving window) through which the value of a given pixel is the result of analysis of the adjacent pixels (geographic neighborhood). A filter of 5×5 pixels was then applied in which the central pixel is calculated as the average of the geographical area or adjacent neighborhood.

This filter was applied to both the derived map of land use and the reference map. This was followed by comparing the vineyard areas with Cohen's concordance index (as done previously): in this case an appropriate conformity was obtained as shown by coefficient $K=0.9699$. This analysis allowed us to validate the test variables (mostly experimental), and confirm that the changes in the vineyards are highly dependent on the slope, their proximity to the main road, their proximity to the wine roads, and their proximity to highly productive vineyards.

The results obtained from this research could be used to support territorial planning decision making, and together with other GIS oriented methodologies it is able to determine environmental and landscaping critical situations. As for example the variables used could be integrated in the study undertaken by Martinuzzi et al. (2007) that developed a classification schema to categorize the relative tendency to sprawl of urban developments by integrating land consumption (population statistics) and land development (high and low density development). The applied methodology could also be an integral part of the analysis conducted by Lopez et al. (2001), in which land cover and land use change was projected forward in the future using Markov chains and regression analyses. The target could be the analysis of relationships between urban growth and landscape change, and between urban growth and population growth. Another GIS study and complementary to the presented model is the one developed by Bernetti and Fagarazzi (2002), in which they have proposed the use of multiple criteria decision analysis in Geographic information to evaluate the possibilities of local development of a territory. The aim being to solve possible conflicts generated from the alternative use of resources: in this case, our methodology brings forward a valid contribution to analysis of possible and alternative land uses.

It is should be stressed that, although the model focuses on a double statistical validation, unfortunately it does not allow overcoming other limitations on CA. One example is the synchronous update of the cells whereas the events that occur at the territorial level have different times from each other, different speed variation and evolution and therefore require different mechanisms for asynchronous update. In addition, the model presents a regular CA, which implies that symmetry in the structure of a determined area is rather unlikely to occur, given that the territory is made up of elements having irregular boundaries and neighborhoods (Cecchini and Rizzi 2003; Blecic et al. 2005).

Conclusions

The study of evolutionary dynamics of the territory cannot be done without relying on the use of spatial software and statistical methodologies. These, combined with GIS offer the opportunity to evaluate and examine the complex relationships characterizing the changes in land use. To this end, one of the most recently used methods involves the use of CA to study these phenomena of transition (Candau 2000; Jenerette and Wu 2001; Sui and Zeng 2001). CA models can be the core of successful integrated spatial models. "Model integration is a deep scientific problem but even so a pragmatic multi-criteria, multi-objective problem. Integrated spatial models can be appropriate tools for tackling integrated spatial policy problems. However, policy models come with a set of requirements of their own distinguishing them rather clearly from research models. Policy makers are most served by models in which the time horizon, the spatial and the temporal resolution are policy problem oriented and not so much process oriented as in research models. They need adequate rather than accurate representations of the processes modeled and sketchy but integral rather than in depth and sector models. While research models are as complicated as necessary and scientifically innovative, the policy maker is better served with an instrument that is as simple as possible and scientifically proven" (Engelen et al. 2002).

Integrated spatial models are increasingly becoming entrenched; accordingly, it is appropriate to emphasize how the results depend strongly on the input data used. The study of the variables involved in the changes of land use is a critical point that often guides these types of analysis. Given the complexity of environmental systems, these variables cannot be considered alone, but multiple variables must be included simultaneously in a given geographical area.

Choosing to use and validate experimental variables involved in land use allows us to study the factors and dynamics of future evolution. The main purpose is not to plan the direction and quantity of expansion (or contraction) of determined crops.

CAs were not used to predict future scenarios, bypassing one of the limitations that accompanies the use of the CA or the lack of statistical validation of results. The main purpose is rather to investigate the reasons behind the occurrence of such expansions (or contractions) in the past, present and future. The selected case study represents a symbolic and traditional Italian agricultural and economic activity. The vineyard has always been regarded as one of the driving forces behind the primary, secondary, and tertiary economic sectors. The examined area of study is one of the most important at the national level in the field of viticulture, offering, therefore, the possibility to generalize the research. Through the variables analyzed, this paper focused on the economic, social, and environmental dimensions, by examining vines from different aspects.

In conclusion, these variables were validated and can be used successively to create plausible scenarios for directing the actors involved in decision making (municipal, provincial, or other public or private levels) to correct planning choices.

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